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CERTIFICATE OF GRANT OF PATENT

In accordance with Section 24(2) of the Patents Act, 1977, it is hereby certified that a patent having the specification No 2278865 has been granted to Baker Hughes Incorporated, in respect of an invention disclosed in an application for that patent having a date of filing of 14 April 1994 being an invention for "Earth-boring bit with improved rigid face seal"

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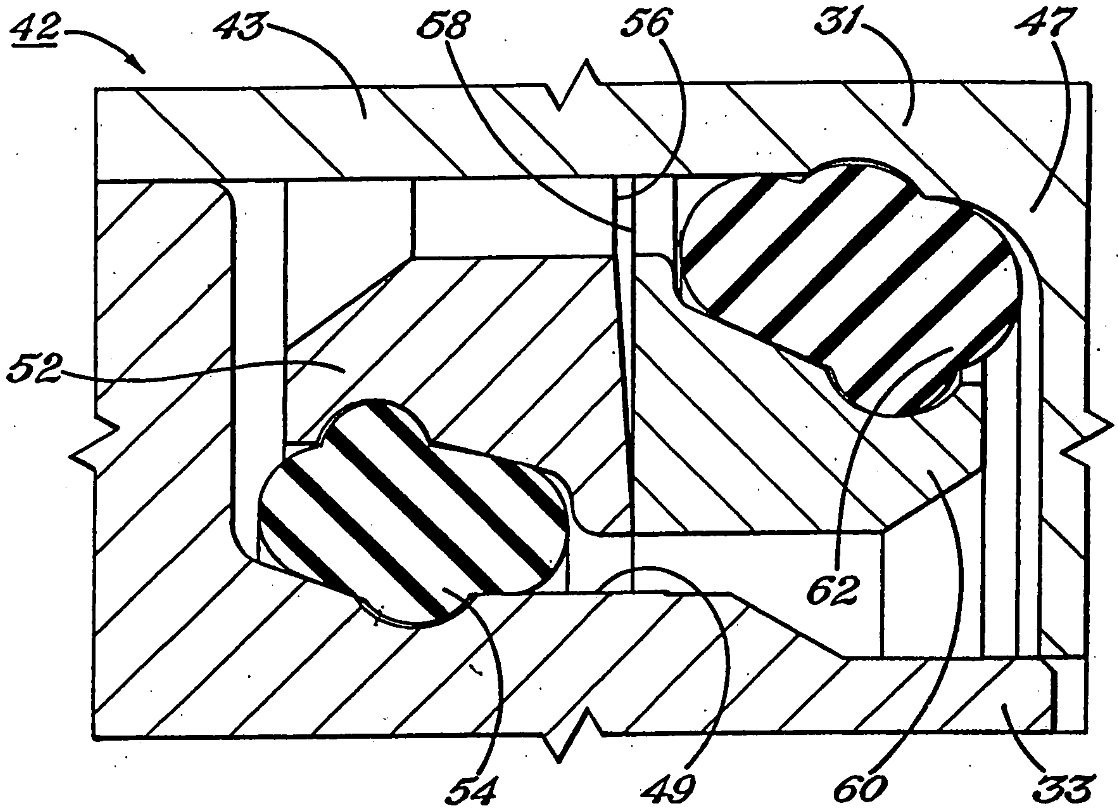
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33

Fig.2

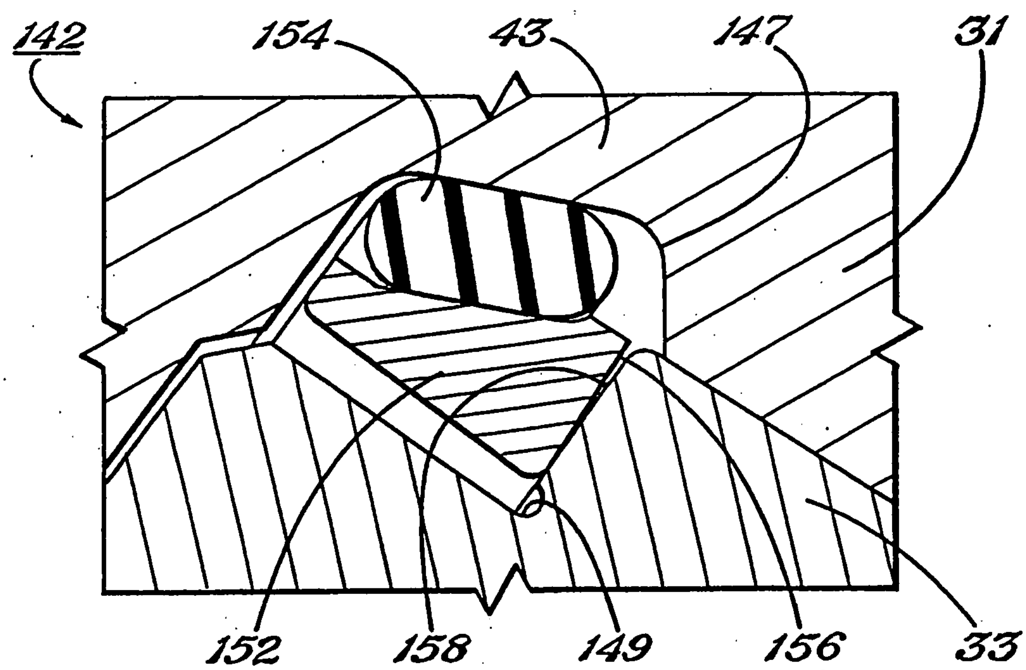
142
154
43
147
31
152
158
149
156
33

Fig.3

2278865

EARTH-BORING BIT WITH IMPROVED RIGID FACE SEAL

cutters mounted on the bit roll and slide upon the bottom of the borehole as the drillstring is rotated, thereby engaging and disintegrating the formation material. The rolling cutters are provided with teeth that are forced to penetrate and gouge the bottom of the borehole by weight from the drillstring.

As the cutters roll and slide along the bottom of the borehole, the cutters, and the shafts on which they are rotatably mounted, are subjected to large static loads from the weight on the bit, and large transient or shock loads encountered as the cutters roll and slide along the uneven surface of the bottom of the borehole. Thus, most earth-boring bits are provided with precision-formed journal bearings and bearing surfaces, as well as sealed lubrication systems to increase drilling life of bits. The lubrication systems typically are sealed to avoid lubricant loss and to prevent contamination of the bearings by foreign matter such as abrasive particles encountered in the borehole. A pressure compensator system minimizes pressure differential across the seal so that lubricant pressure is equal to or slightly greater than the hydrostatic pressure in the annular space between the bit and the sidewall of the borehole.

Early Hughes bits had no seals or rudimentary seals with relatively short life, and, if lubricated at all, necessitated large quantities of lubricant and large lubricant reservoirs. Typically, upon exhaustion of the lubricant, journal bearing and bit failure soon followed. An advance in seal technology occurred with the "Belleville" seal, as disclosed in U.S. Patent No. 3,075,781, to Atkinson et al. Th Belleville seal

Galle's design was in part attributable to the ability of the O-ring design to help minimize the aforementioned dynamic pressure surges.

A major advance in earth-boring bit seal technology occurred with the introduction of a successful rigid face seal. The rigid face seals used in earth-boring bits are improvements upon a seal design known as the "Duo-Cone" seal, developed by Caterpillar Tractor Co. of Peoria, Illinois. Rigid face seals are known in several configurations, but typically comprise at least one rigid ring, having a precision seal face ground or lapped thereon, confined in a groove near the base of the shaft on which the cutter is rotated, and an energizer member, which urges the seal face of the rigid ring into sealing engagement with a second seal face. Thus, the seal faces mate and rotate relative to each other to provide a sealing interface between the rolling cutter and the shaft on which it is mounted. The combination of the energizer ring and rigid ring permits the seal assembly to move slightly to minimize pressure fluctuations in the lubricant, and to prevent extrusion of the energizer past the cutter and bearing shaft, which can result in sudden and almost total lubricant loss. U.S. Patent Nos. 4,516,641, to Burr; 4,666,001, to Burr; 4,753,304, to Kelly; and 4,923,020 to Kelly, are examples of rigid face seals for use in earth-boring bits. Rigid face seals substantially improve the drilling life of earth-boring bits of the rolling cutter variety. Earth-boring bits with rigid face seals frequently retain lubricant and thus operate efficiently longer than prior-art bits.

The invention is set out alternatively in claims 1 and 7.

According to the preferred embodiment of the present invention, the second seal face is a radial seal face on a second rigid seal ring and at least the second seal face portion of the second rigid seal ring is at least partially formed of a super-hard, abrasion-resistant material.

According to one embodiment of the present invention, the second seal face is formed on the cutter of the earth-boring bit and the second seal face is formed of a super-hard, abrasion-resistant material.

The preferred super-hard, abrasion-resistant material is amorphic diamond which has wear-resistance greater than, and a coefficient of sliding friction less than, that of the material of the rigid seal ring.

An example of the invention will now be described with reference to the accompanying drawings in which

Figure 1 is a fragmentary section view of a section of an earth-boring bit.

Figure 2 is an enlarged, fragmentary section view of the preferred seal assembly for use with such earth-boring bits.

Figure 3 is an enlarged, fragmentary section view of an alternative seal assembly, and

Figure 4 is a graphical comparison of the results of a test of friction pairs of material coated according to the present invention versus conventional material.

supplied to journal bearing through passage 27 by pressure-compensating lubricant system 23. Cutter 33 is retained on bearing shaft 31 by means of a plurality of precision-ground ball locking members 41.

A seal assembly 42 according to the present invention is disposed proximally to a base 43 of cantilevered bearing shaft 31 and generally intermediate cutter 33 and bearing shaft 31. This seal assembly is provided to retain the lubricant within bearing cavity 29, and to prevent contamination of lubricant by foreign matter from the exterior of bit 11. The seal assembly may cooperate with pressure-compensating lubricant system 23 to minimize pressure differentials across seal 42, which can result in rapid extrusion of and loss of the lubricant, as disclosed in U.S. Patent No. 4,516,641, to Burr. Thus, pressure compensator 23 compensates the lubricant pressure for hydrostatic pressure changes encountered by bit 11, while seal assembly 42 compensates for dynamic pressure changes in the lubricant caused by movement of cutter 33 on shaft 31.

Figure 2 depicts, an enlarged section view, a preferred seal configuration 42 contemplated for use with the present invention. Seal assembly 42 illustrated is known as a "dual" rigid face seal because it employs two rigid seal rings, as opposed to the single-ring configuration illustrated in Figure 3. Dual rigid face seal assembly 42 is disposed proximally to base 43 of bearing shaft 31 and is generally intermediate cutter 33 and shaft 31. Seal assembly 42 is disposed in a seal groove defined by shaft groove 47 and cutter groove 49. Dual rigid face seal assembly 42 comprises a cutter rigid

energizer ring 154 cooperates with shaft seal groove 147 and rigid seal ring 152 to urge and maintain seal faces 156, 158 in sealing engagement.

At least a portion, and preferably the entirety, of seal faces 156, 158 of seal assembly 142 is formed of super-hard, abrasion-resistant material having a coefficient sliding friction less than that of the material of rigid seal ring 152. Exemplary dimensions for the seal assembly depicted in Figure 3 may be found in U.S. Patent No. 4,753,304 to Kelly.

The seal assemblies depicted in Figures 1, 2, and 3 are somewhat representative of rigid face seal technology and are shown for illustrative purposes only. The utility of the present invention is not limited to the seal assemblies illustrated, but is useful in all manner of rigid face seals.

The super-hard, abrasion-resistant materials contemplated for use with the seal assemblies of the present invention are typically known as "thin-film diamond" or "thin-film diamond-like carbon." These materials are formed primarily of carbon, but are not easily classified because they share characteristics with various forms of carbon, including the crystalline structure of diamond and the amorphous properties of graphitic materials. These materials tend to possess the properties of generally high hardness and wear-resistance, and have low coefficients of sliding friction. These materials are to be distinguished from other low-friction materials such as polytetrafluoroethylene and other fluoroplastics in that they have generally superior wear-

Figure 4 is a graph comparing operating temperature (T), coefficient of sliding friction ($\mu_{sliding}$), and friction force ($F_{friction}$) for a friction pair of conventional material versus a friction pair coated with super-hard, abrasion-resistant material according to the present invention. The test forming the basis for the graph of Figure 4 was conducted pursuant to A.S.T.M. D-2714, and comprised rotating both a conventional, uncoated test ring and a test ring having a coating according to the present invention on a test block of the same respective material (see below) at 196 revolutions per minute for 60 minutes, resulting in 11,760 cycles.

The conventional test ring and block were formed of 440C stainless steel hardened to approximately 52 or higher on the Rockwell C scale. The test ring and block according to the present invention were similarly formed, but were provided with a thin-film (≤ 1 micron thickness) coating of the AMORPHIC DIAMOND® super-hard, abrasion-resistant material.

The test was conducted with 100 milliliters of test lubrication fluid prescribed by the aforementioned A.S.T.M. D-2714 test parameter. The following data was obtained by measuring the aforementioned properties at various time intervals during the test:

lines 200 and 201 represent the measured frictional force (multiplied by a factor of 10) for the conventional friction pair and the friction pair according to the present invention, respectively. Graphed lines 300 and 301 represent the measured coefficient of sliding friction of the conventional friction pair and the friction pair according to the present invention, respectively. As is demonstrated in Figure 4, the friction pair according to the present invention operates at a lower temperature, with a lower frictional force, and with a lower coefficient of sliding friction than the conventional friction pair.

In operation, earth-boring bit 11 is attached to a drillstring (not shown) and run into a borehole for drilling operation. The drillstring and earth-boring bit 11 are rotated, permitting cutters 33 to roll and slide along the bottom of the borehole, wherein inserts or teeth 35 engage and disintegrate formation material. While cutters 33 rotate relative to body 13 of earth-boring bit 11, seal assemblies retain lubricant in bearing cavities 29, promoting the free rotatability of cutters 33 on bearing shafts 31.

Resilient energizer rings 54, 62, 154 maintain rigid seal rings 52, 60, 152 and seal faces 56, 58, 156, 158 in sealing engagement. Seal faces 56, 158 associated with cutter 33 rotate relative to seal faces 58, 156 associated with bearing shaft 31, which remain essentially stationary. Thus, seal faces 56, 58, 156, 158 are in constant sliding contact, and are subject to abrasive and frictional wear.

Rigid face seals having seal faces formed according to the present invention provide increased wear-resistance,

CLAIMS

1. An earth boring bit comprising:

a bit body;

at least one cantilevered bearing shaft, including a base and a bearing surface, extending inwardly and downwardly from the bit body;

at least one cutter mounted for rotation on the cantilevered bearing shaft;

a seal assembly disposed between the bearing shaft and the cutter and proximally to the base of the cantilevered bearing shaft, the seal assembly including at least one rigid metallic seal ring having a seal face in contact with a second seal face, at least one of the seal faces being at least partially formed of a super-hard, abrasion-resistant material.

2. An earth-boring bit as claimed in claim 1 wherein th super-hard, abrasion-resistant material is anamorphic diamond.

3. An earth-boring bit as claimed in claim 1 or claim 2 wherein the second seal face is a radial seal face on a second rigid seal ring, the second seal face being at least partially formed of the super hard, abrasion-resistant material.

4. An earth-boring bit as claimed in claim 1 or claim 2 wherein the second seal face is on the cutter of the earth-boring bit, the second seal face being at least partially formed of the super-hard, abrasion-resistant material.

5. An earth-boring bit as claimed in any one of claims 1 to 4 wh rein at least the s al face of the rigid s al ring and the second seal face ar formed ntirely of super-hard, abrasion-r sistant mat rial.

12. An earth-boring bit substantially as herein describ d with reference to the accompanying drawings.

13. A rigid face seal substantially as herein described with reference to the accompanying drawings.